PARCA 2015
Tuesday, January 27
11:00 AM – 5:30 PM
GSFC Building 33, Room H114

11:00 **Welcome**
Tom Wagner, NASA Headquarters
Charles Webb, NASA Headquarters

11:20 **Goddard Multimedia**
Jefferson Beck, NASA Goddard Space Flight Center

11:30 **KEYNOTE: The Evolution of the Atmospheric Sciences in Service to Society**
James Hurrell, Director, National Center for Atmospheric Research

12:00 **LUNCH** 🍽

01:00 **Linking fjord-glacier dynamics through an investigation of subglacial discharge in West Greenland**
Leigh Stearns, University of Kansas
Emily Shroyer, Orgeon State University

01:20 **Linking Greenland Ice Sheet mass loss to decadal circulation changes in the ocean and atmosphere**
An Nguyen, Massachusetts Institute of Technology

01:40 **Feedback, processes and impacts of contemporary changes in the Arctic**
Sophie Nowicki, NASA Goddard Space Flight Center

02:00 **COFFEE** ☕

02:30 **An historical forcing ice sheet model validation framework for Greenland**
Tom Neumann, NASA Goddard Space Flight Center

02:50 **Beyond backstress: Data driven assessment of outlet glacier dynamics**
Leigh Stearns, University of Kansas

03:10 **Oceans Melting Greenland: A new Earth Venture mission**
Eric Rignot, Jet Propulsion Laboratory

03:30 **Pre-PARCA Greenland Surface Mass Balance (SMB) Meeting (PP-GSM)**
Follow-up closed-door meeting

05:00 **In Memoriam: Alberto Behar**
Eric Rignot, University of California Irvine, Jet Propulsion Laboratory
Larry Smith, University of California Los Angeles

05:30 **POSTER SESSION & COCKTAIL HOUR** 🍸
GSFC Recreational Center

06:30 **DINNER** 🍽
GSFC Recreational Center

POSTER SESSION
Tuesday, January 27
5:30 - 6:30 PM
GSFC Recreational Center

New FOSLS formulation of nonlinear Stokes flow for glaciers
Jeffery Allen, University of Colorado Boulder, Department of Applied Mathematics

We describe two First-order System Least Squares (FOSLS) formulations of a nonlinear Stokes flow model for glaciers and ice sheets. In Glen's law, the most commonly used constitutive equation for ice rheology, the ice viscosity becomes infinite as the velocity gradients (strain rates) approach zero, which typically occurs near the ice surface where deformation rates are low, or when the basal slip velocities are high. The computational difficulties associated with the infinite viscosity are often overcome by an arbitrary modification of Glen's law that bounds the maximum viscosity. In this paper two FOSLS formulations (the viscosity formulation and fluidity formulation) are presented. The viscosity formulation is a FOSLS representation of the standard nonlinear Stokes problem. The new fluidity formulation exploits the fact that only the product of the viscosity and strain rate appears in the nonlinear Stokes problem, a quantity that in fact approaches zero as the strain rate goes to zero. The fluidity formulation is expressed in terms of a new set of variables and overcomes the problem of infinite viscosity. The new formulation is well posed and H1 elliptic away from spatial locations where the velocity gradients are zero. A Nested Iteration (NI) Newton-FOSLS-AMG (algebraic multigrid) approach is used to solve both nonlinear Stokes problems, in which most of the iterations are performed on the coarsest grid. Both formulations demonstrate optimal finite element convergence. However, the fluidity formulation is more accurate. The fluidity formulation involves linear systems that are more amenable to solution by AMG, requiring only 1/27 of the computational effort for the same level of residual reduction as the viscosity formulation, for the test problem considered. Further improvement in computational cost was achieved using adaptive refinement via ACE.

Supraglacial and subglacial hydrologic variability in the Paakitsoq Region, Western Greenland
Lauren C. Andrews, University of Texas at Austin, Institute for Geophysics

The nature of the subglacial hydrologic system within the ablation zone of the Greenland Ice Sheet modulates surface-melt-driven perturbations to ice velocity. The continual evolution of this system results in non-linear relationships between surface melt and ice velocity and uncertainty regarding its effect on ice-mass loss in a warming climate. Recent modeling suggests that both low surface slopes and supraglacial melt production limit the development of subglacial channels that can efficiently drain surface melt and reduce the melt–acceleration feedback. However, these models are rarely constrained by observations of the supraglacial and subglacial hydrologic systems, i.e., the key sources and sinks of local meltwater. Here we use meteorological observations (surface ablation and temperature), moulin locations (identified in Worldview-2 imagery) and high-resolution surface topography to produce supraglacial discharge curves for moulin-defined surface-drainage basins in the Paakitsoq region of western Greenland during the 2011 and 2012 summer melt seasons. These discharge curves are combined with subglacial hydropotential and borehole observations of basal sliding to explore the evolving drainage efficiency of the subglacial hydrologic system. We further evaluate the relative importance of basal sliding and surface melting in maintaining efficient subglacial pathways over the course of the melt season.

Multi-disciplinary observations of iceberg calving at Rink Isbrae, West Greenland

Timothy Bartholomaus, University of Texas at Austin, Institute for Geophysics

Changes in the rates of calving from tidewater glaciers can be a tremendous driver of glacier and ice sheet mass balance change. However, the challenge of making observations within the extremely dynamic region of the glacier terminus has limited our understanding of these processes.

Here we will report on the glacier and ocean response to large calving events at Rink Isbrae on the west coast of Greenland. We combine ground based radar interferometry, seismology, and timelapse imagery, to document rotational, bottom out calving events, up to 300 m x 3000 m x 700 m in size. Moored observations of ocean currents and temperatures demonstrate the calving event's effect on the fjord waters. Radar data reveal that full thickness calving events can be preceded by over 6 hrs of increasingly rapid motion of rifting ice block towards the ocean, as an iceberg begins to separate from the rest of the glacier. During the minutes surrounding one calving event, we observe brief reversals in the motion of the ungrounded terminus and increases in speed by 50%. Seismically recorded horizontal ground motion on bedrock 2.7 km from the calving event exceeded 2.5 cm/s for several seconds during the iceberg's eventual rotation away from the terminus. Approximately 70 minutes after the calving event, a mooring 10.3 km distant from the terminus recorded a several-minute surge in the out-going current speed, followed by a second surge 60 minutes later. This second surge swept to 600 m depth over the 45 minutes following its arrival at the surface.

Ice debris from the largest calving event filled a 40 km^2 region of the formerly ice-free proglacial fjord, freezing it into a rigid ice mélange. This mélange persisted for 4 days until it began to break apart during a strong katabatic wind event. MODIS imagery reveals that at least three similar mélange-forming events happened during summer 2014.

Through the combination of multiple lines of evidence, we are able to work towards a more complete view of the processes controlling the rates of iceberg calving from tidewater glaciers and their effect on the ocean.

Moisture flux differences in Greenland between 2012 and 2013 and how it affects surface melt

Linette Boisvert, NASA Goddard Space Flight Center
Earth System Science Interdisciplinary Center, University of Maryland College Park

The moisture flux (i.e. evaporation) plays an important role in the Arctic energy budget, the water-vapor feedback and Arctic amplification, but is one of the most uncertain variables. During the past decade, the sea ice cover has been rapidly declining and with this change a larger amount of water vapor has been put into the lower atmosphere via an increase in the moisture flux. This increase in atmospheric moisture could, through the water vapor feedback and greenhouse effect, cause increased near surface atmospheric warming, which in turn could cause an increasing in Greenland ice sheet surface melt. In this study, we compare moisture flux rates from 2012, a high surface melt year, to 2013, a normal surface melt year, in order to determine if changes in the amount of latent heat flux energy and the moisture flux into the ice sheet surface are helping to cause changes in surface melt events. The moisture flux is calculated using data from the Atmospheric Infrared Sounder (AIRS) in the *Boisvert et al.* [2013] moisture flux scheme. Trends in the moisture flux between 2003-2013 are also examined in the seas surrounding Greenland to see in changes in the moisture flux and moisture transport from these seas onto the ice sheet can be linked to anomalous melt events.

The 2012 record melt over the Greenland ice sheet led to an anomalous ocean freshening

Ludovic Brucker, NASA Goddard Space Flight Center
Universities Space Research Association

The Greenland Ice Sheet (GIS) influences the Earth's climate through the release of freshwater into the ocean. With an increasing melt water runoff (estimated to account for >50% of the GIS mass loss), the freshwater input may at first change the salinity of the seas surrounding Greenland. Using the Goddard Earth Observing System (GEOS-5) assimilation and forecast model, melt water volume was simulated for each drainage basin of the Greenland ice sheet. The five largest volumes of water are produced on the West coast of Greenland. Thus, most of the freshwater is released in Baffin Bay.

For this poster, we analyze the sea surface salinity (SSS) and its anomalies in 2012 when the Greenland ice sheet experienced a melt record. By combining Aquarius satellite retrievals and in-situ observations with GEOS-5 coupled modeling and assimilation experiments, we focus on the anomalous freshening of the Baffin bay and Labrador sea that lasted until the fall 2012. The unusually large volume of fresh water that ran off the GIS was advected downstream by the west Greenland current and created a large fresh water intrusion into the North Atlantic current. Using tracers released in GEOS-5 at the location of the GIS runoff, we also quantify the runoff contribution to this large fresh water intrusion. By combining observations and modeling tools, we will eventually be able to assess the uncertainties in both the runoff and the ocean SSS (a by-product of the assimilation).

Simulation of aerosols over the Arctic with the NASA GEOS-5 Earth System Model

Peter Colarco, NASA Goddard Space Flight Center

Aerosols are implicated in issues related to air quality and climate change, the latter via the aerosol direct (i.e., radiative) and indirect (i.e., microphysical) effects. In the case of the aerosol direct radiative effects the presence of scattering (i.e., reflecting) and absorbing aerosols within the atmospheric column affects the column radiation balance. This leads to, typically, a cooling of the surface, and can lead to warming aloft if the aerosols are absorbing, which may be strongly enhanced over bright surface, such as in the Arctic. Most aerosols are generated in the tropics or mid-latitudes. The impact of aerosols on the Arctic climate system is thus complicated by the diverse sources and compositions of aerosols transported to the Arctic, their pathways and resulting vertical distributions, and particular aspects of the Arctic system itself, including low sun angle—leading to long path lengths for radiative effects—and the presence of a reflective surface boundary condition. For the surface reflectance there is an additional modulation in that deposition of aerosols to bright snow and ice surfaces can result in a darkening of the surface, leading to an enhanced surface warming.

We present simulations of global aerosol distributions performed in the NASA GEOS-5 Earth system model. GEOS-5 includes an aerosol module based on the Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) model, which simulates emissions, transport, radiative effects, and deposition of dust, sea salt, sulfate, and carbonaceous aerosols from natural and man made sources. Results of two sets of simulations are presented. The first in based on the MERRA-2 joint atmospheric and aerosol reanalysis, and includes assimilation of aerosol data. This provides a data constrained baseline for aerosol distributions in the modern era (i.e., 1980 - present). A complementary simulation using historical and estimated future emissions is presented for the years 1960 - 2100, which shows how aerosol composition and hence radiative effects of aerosols in the Arctic are expected to change over the coming century.

NSF-supported research, infrastructure and logistics in Greenland
Renee Crain, National Science Foundation, Division of Polar Programs

The National Science Foundation supports 40-50 research projects in Greenland each year. Studies include understanding the dynamics and mass balance of the Greenland Ice Sheet, atmospheric chemistry, deep-ice core research, and archaeological excavations of Norse settlements. The Arctic Mapping Application (ARMAP; http://armap.org) is a searchable visualization tool that provides more information on the projects, investigators and locations of research. NSF supports traineeships for Greenlandic students and the Joint Science Education Project (JSEP) that sends Greenlandic, Danish and U.S. teachers and students to Greenland for several weeks of scientific research. To enable research in Greenland, the Arctic Research Support and Logistics program maintains a research facility at the summit of the Greenland Ice Sheet, Summit Station, and supports numerous field camps on the ice sheet each year, in close coordination with the Government of Greenland. Kangerlussuaq and Thule Air Base are research support hubs to support Summit Station and field campaigns. NSF uses the 109th Airlift Wing of the U.S. Air National Guard to support operations in Greenland with ski-equipped LC-130 aircraft. In addition, NSF operates an overland traverse using large agricultural tractors and specially engineered sleds and fuel bladders to haul cargo and fuel to Summit Station and other locations on the Greenland Ice Sheet. Remote communications, helicopter and fixed-wing aircraft, small boats and other resources are available to NSF-funded researchers and to other agencies on a collaborative or reimbursable basis to support research in Greenland.

Characterization of recent Greenland melt events in atmospheric analyses and satellite data
Richard I. Cullather, NASA Goddard Space Flight Center
Earth System Science Interdisciplinary Center, University of Maryland College Park

Data from a variety of observational and modeling sources have indicated enhanced, widespread melting of the Greenland Ice Sheet (GrIS) surface in recent years. In 2012, this melting was punctuated by the circumstance on 11 July when almost the entirety of the ice sheet simultaneously experienced surface melt, including Summit. While such an event has been considered as the result of unique meteorological conditions, the melting record for the season also occurred in 2012 based on spatial extent and duration. Previous melt extent records also occurred in 2002, 2007, and

2010. Melt extent may be estimated from remote sensing methods, but runoff volume may only be obtained from select in situ measurement locations or modeling methods. The aim of this study is to assess differences in available estimates of melt extent and runoff volume, and to characterize the spatial and temporal variability of surface melt. The GEOS-5 global atmospheric model with an improved surface representation for the GrIS is replayed against the NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA) to produce an historical reanalysis. The use of GEOS-5 offers the potential for applying a global model with a realistic GrIS surface representation for the assessment of melt events and their relation to the large-scale climate. These values are compared with output from the Modèle Atmosphérique Régional (MAR) regional climate model, the Arctic System Reanalysis (ASR), global analyses and remote sensing data. The approach is to spatially average values by drainage basins and evaluate the resulting time series. Seasonally, numerical analyses and models typically indicate less melt coverage during the early summer and more in late summer in comparison to passive microwave data. The relation between melt area, melt duration, and runoff volume differs markedly by drainage basin, with a greater amount of estimated runoff per melt area occurring in southern drainage basins while northern basins are characterized by shorter duration melt periods and a larger percentage of the basin area experiencing melt. An assessment of differences in the spatial and temporal variability of surface melt during enhanced melt years is presented.

Using IceBridge laser altimetry data and a positive degree day melt model to capture present day mass balance rates of Russell Glacier, Greenland
Indrani Das, Columbia University, Lamont-Doherty Earth Observatory

Recent studies have documented strong warming along the west coast of Greenland. Surface mass balance (SMB) models also estimate a more negative SMB since the 1990s, associated with increased runoff and melt not compensated by the increased precipitation. While warmer summer conditions lead to more melt, warmer winter conditions may change the precipitation patterns with more rain events over snow events. Together the summer and winter time warming changes the surface accumulation, melt and freeze patterns, water retention in the firn pack, surface albedo and grain size, and thermal characteristics of ice by retaining more heat thereby inducing a faster onset of melt period. Most of the surface processes that impact surface melt occur on relatively smaller scales that are not captured by the coarser resolution climate models. There is a need to develop higher resolution models that can be integrated with satellite and airborne datasets to capture the present day change of the Greenland ice sheet.
In this study, we will present preliminary results of surface melt and mass balance rates using a positive degree day melt model and IceBridge ATM data over Russell Glacier, Greenland. The melt model is calibrated and validated using surface mass balance rates from the K Transect. We will integrate this melt model with satellite images and IceBridge geophysical datasets to study the impacts of changing surface albedo on surface melt of the Greenland ice sheet.

Large area mapping of ice sheet flow from persistent surface texture patterns using Landsat 8
Mark Fahnestock, University of Alaska Fairbanks, Geophysical Institute

The advent of frequent repeat moderate resolution satellite coverage by visible-band sensors enabled the birth of satellite-image-based tracking of ice sheet flow in crevassed ice just over twenty years ago. Following this, rapid development of

techniques making use of imaging radars brought wide-area ice flow mapping based on satellite-borne synthetic aperture radar coverage. We report on the maturation of satellite-borne visible-band mapping of ice flow over large areas on ice sheets as enabled by the high radiometric resolution and geolocation accuracy of Landsat 8 imagery. Here we demonstrate the application of Landsat 8 imagery to mapping ice sheet flow extending into the interiors of Antarctica and Greenland. The very high radiometric resolution of Landsat 8 enables tracking displacement of small image chips distinguished by subtle local patterns on the uncrevassed surface of the ice sheet at ~100-meter spatial scale across imagery separated by multiple orbit cycles. We utilize simple spatial filtering techniques, including an enhanced implementation of normalized cross-correlation. The result is a densely sampled map of surface motion that rivals the coverage from speckle tracking and interferometry of SAR imagery. Using the correlation techniques common to IMCORR (Scambos et al., 1992) and later software, modern image libraries and single-CPU hardware, we are able to process full Landsat 8 scene pairs in a few minutes, allowing comprehensive analysis of ~4K available ice sheet image pairs for a season in Antarctica in a few days.

Mass balance of Greenland from combined CryoSat, Envisat and GRACE inversion
Rene Forsberg, Technical University of Denmark, National Space Institute

With 12 years of GRACE satellite data now available, the ice mass loss trend of Greenland are clearly demonstrating ice mass loss in marginal zones of the ice sheets, and accelerating trends in some regions such as the north-west marginal area. Although the GRACE release-5 products have provided a significant increase in resolution, the detailed space-based detection of where the ice sheet is loosing mass needs to come from other sources, notably satellite altimetry, which point out the detailed location of areas of change, and – when combined with firn compaction and density models – also can be used to infer mass changes. In the paper we outline mass change results from Greenland 2003-14 as determined from Envisat, CryoSat and GRACE, highlighting the increasing melt in the marginal zones both in NW and NE Greenland, and with a special focus on the melt anomaly years of 2012 (record mass loss) and 2013 (no mass loss).

Glacier mass loss in Alaska from airborne lidar altimetry
Chris Larsen, University of Alaska Fairbanks, Geophysical Institute

The University of Alaska Fairbanks LiDAR Altimetry Program has flown repeat surveys of glaciers in Alaska from 1994 to 2014 and has made direct assessments of glacier mass balance on 46% of Alaska's glacier area and 81% of the tidewater glacier area. We reconstruct regional mass balance using collective estimates of individual glacier mass balance and combine these data with calving rate estimates to assess the relative roles of surface mass balance and iceberg calving on the mass balance of the Alaska region.

AIRS surface temperature and its relation to Greenland Ice Sheet mass
Jae N. Lee, NASA Goddard Space Flight Center
Joint Center for Earth Systems Technology, University of Maryland Baltimore County

Amongst other accelerating feedbacks on the Greenland Ice Sheet (GrIS) melt, surface temperature is probably the most effective variable for the evaluation of the Greenland environment. Surface skin temperature (Ts) data from Atmospheric

Infrared Sounder/Advanced Microwave Sounding Unit-A (AIRS/AMSU) are analyzed to study the relationships between surface temperature variations over the Greenland Ice Sheet (GrIS) and mass loss measured by Gravity Recovery and Climate Experiment (GRACE) since 2004. A 'melt area index', defined as the weighted area where the surface skin temperature is 273K in southern Greenland, correlates well with the seasonal and interannual variations of GrIS mass estimated from GRACE. During the unprecedented GrIS mass anomaly in 2012, the index spiked over Greenland. On the other hand, the mean surface temperature in southern Greenland does not correlate directly with the GrIS mass anomaly. Instead, the GrIS mass anomaly lags the temperature by ~2 months. Rapid response of GrIS mass change to 'melt area index' indicates that large scale surface melt can be triggered by warm surface temperature 273K, and that surface melt was instantly followed by GrIS mass loss. Our results suggest that GrIS mass loss is vulnerable to the area of Greenland which experiences surface melting, but the average temperature rise begins two months prior to the large scale melt. Reliable near term trends and characterization of surface temperature variability is important to assess GrIS mass loss, since surface temperature plays a critical role in ice-sheet mass loss.

The FirnCover Project and Community Firn Model: A data-driven open source assessment of firn compaction in Greenland

Mike MacFerrin, University of Colorado Boulder, Cooperative Institute for Research in Environmental Science

An unavoidable source of uncertainty in altimetry-based ice sheet mass balance estimates is the rate of firn compaction directly affecting the conversion from volume to mass. The Firn Model Inter-Comparison Experiment has shown that published firn compaction models vary widely when estimating firn density under a steady state climate, and that their responses to changing climates are variable enough to potentially exceed the current mass balance signal of the entire Greenland ice sheet. Here we present initial results from the Firn Compaction Verification and Reconnaissance ("FirnCover") project measuring fluctuations in firn compaction at three locations in Greenland's percolation zone since 2013, and the implications these measurements have on mass balance estimates. The FirnCover network will soon expand to ten locations spanning all of Greenland's climate conditions. Its measurements will force a Community Firn Model that contains nine published compaction models within a single open-source framework that will be made publicly available to the scientific community. By releasing independent firn models while simultaneously validating them in parallel against an expansive in situ dataset, the FirnCover project and Firn Community Model provide a strong opportunity to significantly narrow the largest source of uncertainty in altimetry-based mass balance measurements of the Greenland ice sheet.

Radar constraints on basal sliding beneath and englacial temperature within the Greenland Ice Sheet

Joseph A. MacGregor, University of Texas at Austin, Institute for Geophysics

Two outstanding questions for both polar ice sheets are: 1. Where is ice flow primarily due to basal sliding? 2. What is the ice sheet's modern temperature structure? These questions affect interpretation of modern patterns of ice-sheet surface velocity and fundamental understanding of their dynamics. Models can predict both basal sliding rates and englacial temperature, but are difficult to verify. Here we address these questions for the Greenland Ice Sheet (GrIS) using its recent dated radiostratigraphy. First, Dansgaard–Johnsen models of Holocene depth–age relationships are related to the shape factor, which is the ratio of the depth-averaged horizontal velocity to the surface velocity. Where the shape factor approaches unity, horizontal ice motion must be primarily accommodated at or near the bed. Three distinct regions of basal sliding are apparent within the GrIS: the northeastern drainage basin that includes the Northeast Greenland Ice Stream, a divide-straddling region northeast of Camp Century and the southwestern drainage basin west of DYE-3. Second, englacial dielectric attenuation rates, inferred from the echo intensity of mapped reflections, constrain depth-averaged englacial temperature across the GrIS. South of 70ºN, englacial temperature is substantially lower than modern surface temperature, implying that the "cold plug" previously observed at the ice-sheet periphery is more widespread than predicted and is likely also related to past changes in surface boundary conditions. These new inferences are potentially powerful constraints on GrIS dynamics, and they should be used to evaluate and improve the next generation of ice-sheet models.

Cloud and boundary layer processes over Greenland from the MERRA2 reanalysis

Andrea Molod, NASA Goddard Space Flight Center
Earth System Science Interdisciplinary Center, University of Maryland College Park

The Global Modeling and Assimilation Office at the Goddard Space Flight Center is nearing the completion of a new long term global reanalysis, called MERRA2. The MERRA2 data assimilation system is improved over the MERRA system due to developments relevant for the Arctic in the underlying atmospheric model, and due to the use of modern (hyperspectral) satellite data. MERRA2 reanalysis fields are used here to study the Greenland temperature and melt anomalies during the 2012. in contrast to the more climatological 2013 season. Atmospheric heat budgets are examined, which include vertically integrated heat transport, cloud radiative forcing, and boundary layer turbulent heating.

Bimodal albedo distributions in the ablation zone of the southwestern Greenland Ice Sheet

Samiah Moustafa, Rutgers University, Department of Geography

Surface albedo is a key variable controlling solar radiation absorbed at the Greenland Ice Sheet (GrIS) surface, and thus meltwater production. Recent decline in surface albedo over the GrIS has been linked to enhanced snow grain metamorphic rates and amplified ice-albedo feedback from atmospheric warming. However, the importance of distinct surface types on ablation zone albedo and meltwater production is still relatively unknown, and excluded in surface mass balance models. In this study, we analyze albedo and ablation rates (m d^{-1}) using in situ and remotely-sensed data. Observations include: 1) a new high-quality in situ spectral albedo dataset collected with an Analytical Spectral Devices (ASD) spectroradiometer measuring at 325–1075 nm, along a 1.25 km transect during three days in June 2013; 2) broadband albedo at two automatic weather stations; and 3) daily MODerate Resolution Imaging Spectroradiometer (MODIS) albedo (MOD10A1) between 31 May and 30 August. We find that seasonal ablation zone albedos have a bimodal distribution, with two alternate states. This suggests that an abrupt switch from high to low albedo can be triggered by a modest melt event, resulting in amplified ablation rates. Our results show that such a shift corresponds to an observed melt rate percent difference increase of 51.6% during peak melt season (between 10–14 July and 20–24 July, 2013). Furthermore, our findings demonstrate that seasonal changes in GrIS ablation zone albedo are not exclusively a function of a darkening surface from ice crystal growth, but rather are controlled by changes in the fractional coverage of snow, bare ice, and impurity-rich surface types. As the climate continues to warm, regional climate models should consider the seasonal evolution of ice surface types in Greenland's ablation zone to improve projections of mass loss contributions to sea level rise.

Resolving bathymetry from airborne OIB gravity along Greenland fjords
David Porter, Columbia University, Lamont-Doherty Earth Observatory

Operation IceBridge (OIB) has performed extensive airborne gravity surveys of Greenlandic fjords in order to model the bathymetry in areas that are otherwise difficult to survey. Bathymetry models for 56 of the 93 fjord-profiles surveyed by OIB from 2010-2012, along with a series of coast-parallel survey lines in Northwest Greenland, are available at the National Snow and Ice Data Center as a Level 4 IceBridge product (http://nsidc.org/data/igbth4). These models, which resolve bathymetry at ~5 km wavelengths to an accuracy of 50-200 m, have been constructed by combining ice surface and thickness data from coincident OIB lidar and radar surveys. Inversion of gravity data allows us to estimate depths to the grounding line in areas with poor radar returns and identify sill depths and overdeepenings in the fjords.

Bathymetry has been a missing piece in understanding ice-ocean interactions of marine-terminating glaciers in Greenland as it affects the flow of warm Atlantic Water to the termini of tidewater glaciers. A case study of Tracy and Heilprin Glaciers, a pair of neighboring glaciers in northwest Greenland, shows that though exposed to similar external forcings, the glacier with the deeper grounding line has retreated more rapidly. This new comprehensive mapping of grounding line depths from OIB gravity inversions provides the basis for examining this question for many of Greenland's largest glaciers. We find that, in general, glaciers with a deeper grounding line are more sensitive to large-scale ocean forcing.

Identifying the links between sea-ice distribution and the biogeochemistry of the Arctic Ocean
Cecile S. Rousseaux, NASA Goddard Space Flight Center
Universities Space Research Association

Changes in the amount and timing of the primary production will have a big impact on the transfer of energy through the Arctic food chain including birds, fish and mammals in this region. By using state-of-the-art models, including the NASA Ocean Biogeochemical Model and GEOS-5, we conduct sensitivity analysis and assess the impact of these various processes on biogeochemical cycles in this region. More specifically we assess and quantify how the processes that affect the total mass balance of the ice sheet (changes in precipitation and run off) and sea-ice distribution impact nutrient composition, total chlorophyll, phytoplankton composition and primary productivity. We provide some preliminary data that indicate some clear interannual variability in both the nutrients and the phytoplankton populations for the period from 1998-2010. These results improve our understanding of how the processes associated with ice sheet melting impact the biogeochemical cycles and improve our understanding of the biological and biogeochemical impacts of ongoing and future changes in the Arctic Ocean.

Uncertainty quantification of Greenland Ice Sheet mass balance: a comparison between a GRACE mascon solution and ISSM

Nicole-Jeanne Schlegel, University of California Los Angeles
Jet Propulsion Laboratory

Quantifying Greenland's future contribution to sea level rise is a challenging task and requires accurate estimates of ice flow sensitivity to climate change. Transient ice flow models are promising tools for estimating future ice sheet behavior. However, confidence in these types of future projections is low, especially because evaluation of model historical runs is so challenging due to the scarcity of continental-wide data for validation. Here, we take advantage of a new high-resolution (~300 km) monthly mascon solution for the purpose of mass balance comparison with an independent, historical ice flow model simulation using the Ice Sheet System Model (ISSM). The comparison highlights which regions of the ice sheet differ most from GRACE. Investigation of regional differences in trends and seasonal amplitudes between simulations forced with three different Regional Climate Model (RCM)-based estimates of surface mass balance (SMB) allows us to make conclusions about the relative contributions of various error sources in the model hindcast. Conclusions will aid in the improvement of RCM SMB estimates as well as ice sheet simulation estimates of present and future rates of sea level rise. This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration's Cryosphere Program and President's and Director's Fund Program.

Comparison of model temperatures to NOAA in situ data at the Greenland Summit

Chris Shuman, NASA Goddard Space Flight Center
Joint Center for Earth Systems Technology, University of Maryland Baltimore County

In our study, two temperature values were extracted from model data fields for comparisons to NOAA's near-surface temperature data at the Greenland Summit. For each model, a 2-m temperature (interpolated between the surface and 1st model layer) and the modeled surface temperature were extracted. Five models were studied for the following dates, resolutions, grid sizes, and model elevations. The models investigated are: 1) NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA, 2008-2013, 1 hr, ½ deg. lat. by 2/3 deg. lon., 3184.94 m); 2) MERRA-Replay, (2008-2013, 3 hr, 1 degree, 3157.2 m); 3) the Ohio State University's Arctic System Reanalysis (ASR, 2008-2012, 3 hr, 30x30 km, 3121.75 m); 4) the NCEP Climate Forecast System Reanalysis (CFSR, 2008-2009, 6 hr, ~0.25 degree, 3167.99 m); and 5) the ECMWF-Interim Re-Analysis (ERAI, 2008-2014, 6 hr, ~1/2 degree, 3168.78 m). Temperature comparisons were done by aligning the closest 1-minute mean temperatures from the in situ sensor with the model temperatures (all times are UTC).

Preliminary results were assessed primarily from scatter plots and detailed temperature comparisons during the unusual July 2012 melt event at Summit. Our results show considerable spread in the modeled temperatures across the annual temp range (±10K) relative to the NOAA data. Curiously, the 2-meter temperatures are typically at a different slope than surface temperatures (i.e. rotation of the point cloud). In general, MERRA surface temperatures are too cold whereas the 2-m temperatures are too cold at the upper end of the temperature range and too warm at the low end (point cloud rotation). ASR surface temps are too cold at the lower end and slightly too warm at the upper end and also have an imposed 273.15 K

maximum temperature at this location. ASR 2-meter temperatures are very close to the NOAA values overall but have a curving structure to the point cloud across the temperature range. CFSR surface temperatures are slightly warm at the low end, and too cool at the high end while the 2-meter temperatures exaggerate this offset (rotation). ERAI surface temps are slightly too warm at the low end but are fairly close across the full range but their derived 2-meter temps become even warmer at low end of the range. Additional analyses are anticipated including assessing if the elevation differences between the gridded data and the in situ instruments can explain some of the observed differences.

Insights from thermo-mechanically coupled modeling of high-elevation regions of the Greenland Ice Sheet

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As observations become more plentiful through remote sensing and numerical models become more sophisticated, a clear priority of the ice sheet modeling community is to compare model simulations with observations. Temperature and velocity conditions within the Greenland ice sheet and at the bed remain largely unknown with the exception of sparse borehole measurements, but much can be inferred from rigorous thermo-mechanically coupled modeling. Surface velocities on the Greenland ice sheet are well constrained, both from satellite imagery and field observations. We take advantage of the observed surface velocities at the PARCA stakes around the 2,000m elevation contour of the ice sheet as modeling targets that represent a broad range of flow characteristics in different regions. Prescribing ice geometry, we use a two-dimensional thermo-mechanically coupled model to calculate 'steady-state' velocity and temperature profiles throughout the depth of the ice along flowlines from the main divide to the 2,000m elevation contour. Vertical velocity calculations are based on first principles of mass conservation, and the enthalpy-based temperature calculations also incorporate the effects of liquid water content in temperate ice through the flow law parameter. Using a relatively simple model gives us the freedom to explore multiple sensitivities. Numerous insights from our simulations are presented for different regions, such as the influence of variable geothermal flux, the treatment of basal boundary conditions, and appropriate enhancement factors based on the age of ice. Also highlighted is the importance of including temperature calculations in ice sheet modeling. Results indicate that areas of temperate bed do exist in the high-elevation interior in certain sections of Greenland.

CALIOP observations of transparent and opaque clouds: Implications for Arctic and Greenland surface warming

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Cloud radiative effects on surface warming are complicated by their macro- and micro-physical properties (e.g., thermodynamic phase, optical thickness, and particle size). Low-level transparent liquid clouds can act more effectively than opaque clouds in warming the surface during sunlit hours, because they are thin enough at short-wavelength (SW) to allow solar radiation in to heat the surface and thick enough at long-wavelength (LW) to prevent surface radiation from leaving atmospheric boundary layer (ABL). This "cloud greenhouse" effect is thought to play a key part in Arctic sea ice loss and Greenland ice sheet melt [Bennartz et al., 2013]. In this study we analyze the cloud data acquired by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) during 2008-2014 to quantify the distribution and amount of transparent and opaque clouds over the Arctic and Greenland in different seasons. The satellite observations show that transparent clouds dominate (30-60%) the December-February (DJF) season over the Arctic Ocean with majority of ice clouds but reduce to ~10% during the June-August (JJA) season when liquid clouds are common. The transparent and opaque cloud amount over Greenland during JJA has a similar partition with ~10% and 50% respectively. Thus, the small amount of transparent clouds in JJA are likely to provide only limited contributions to surface warming through the potential “cloud greenhouse” effect, compared to the albedo effects from the ~30% clear sky and ~50% optically-thick clouds. However, the “cloud greenhouse” effect may have a significant role in enhancing land surface warming during the warm seasons when low-level liquid clouds are present. Studying the surface temperature observed by Atmospheric Infrared Sounder (AIRS), we find that the region with more transparent clouds tend to have a warmer surface during the day.

The Ultra-Wideband Software-Defined Radiometer (UWBRAD) for Greenland Ice Sheet internal temperature sensing

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In general, the brightness temperature (Tb) obtained by a microwave radiometer can be related to thermal emissions from the entire vertical column of the ice sheet, so that the vertical temperature profile affects the measured brightness temperature. Initial studies have shown that subsurface temperature information impacts the 1.4 GHz brightness temperature observations of ESA’s Soil Moisture Ocean Salinity (SMOS) instrument. Existing spaceborne radiometers at frequencies less than 2 GHz (SMOS and NASA’s Aquarius) use a single 1.4 GHz frequency. The Ultra-Wideband Software-Defined Radiometer (UWBRAD) is currently being developed at ElectroScience Lab, the Ohio State University under the support of the NASA Instrument Incubator Program (IIP). The UWBRAD instrument will provide measurements of ice sheet thermal emission over the frequency range 0.5-2 GHz for the purpose of remotely sensing internal ice sheet temperature information. The system is currently under development and expected to be deployed in airborne observations of Greenland in 2016.

A ’geometric’ downscaling method for coupling dynamical ice sheet models to GEOS-5

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A plausible projection of future sea level rises requires coupled AOCGMs to include a dynamic ice sheet model (ISM) component. Getting the right forcing to the ice sheet models plays a critical role in the coupling process. The issue is further complicated by the mismatch between the grids used by the atmosphere and ice sheet. Typically surface mass balance (SMB) and temperature fields are downscaled from the coarse atmospheric grid to the fine ice grid. We present one technique employed to couple NASA Goddard GEOS5 AGCM to JPL Ice Sheet System Model (ISSM). The Greenland ice surface from ISSM is explicitly embedded in the GEOS5 AGCM grid with a 'tile' representation. Atmospheric forcing fields are interpolated and further adjusted to account for elevation differences and fed into a SMB model operating on ice surface tiles. The coupling is done in such a way that mass and energy are conserved. The proposed method is independent of the underlying ice grid and can be used to couple any ISM. Comparison of resultant downscaled SMB fields with that from a 7-km resolution Nature Run will be discussed.